Optics for Diagnostic Section BC1 in the European XFEL

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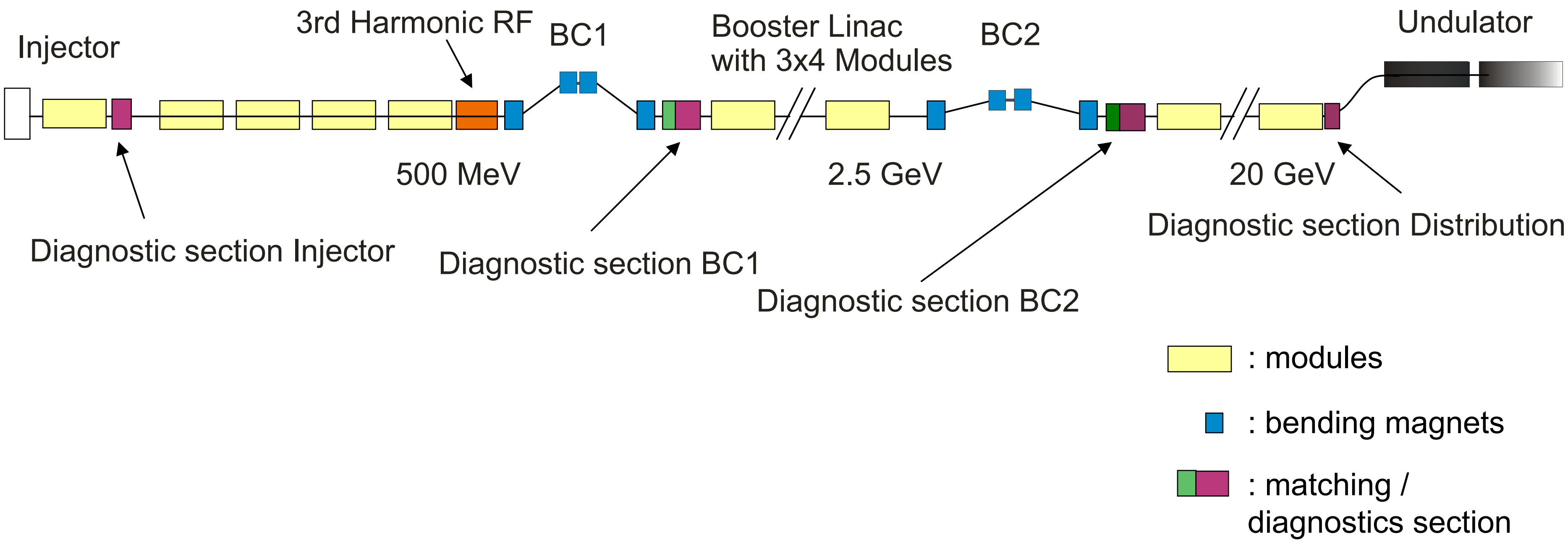
Outline

– Overview
– Optimisation for slice emittance measurements
– Lattice layout
– BC1 Spectrometer/Dump section
– Outlook / Questions

Sneak preview for XFEL Lattice Review (Nov 2006)

- Are we on the right track?
- Have we overlooked anything important?
- What else need to be studied?

XFEL Diagnostic Sections



Demands on the diagnostic section

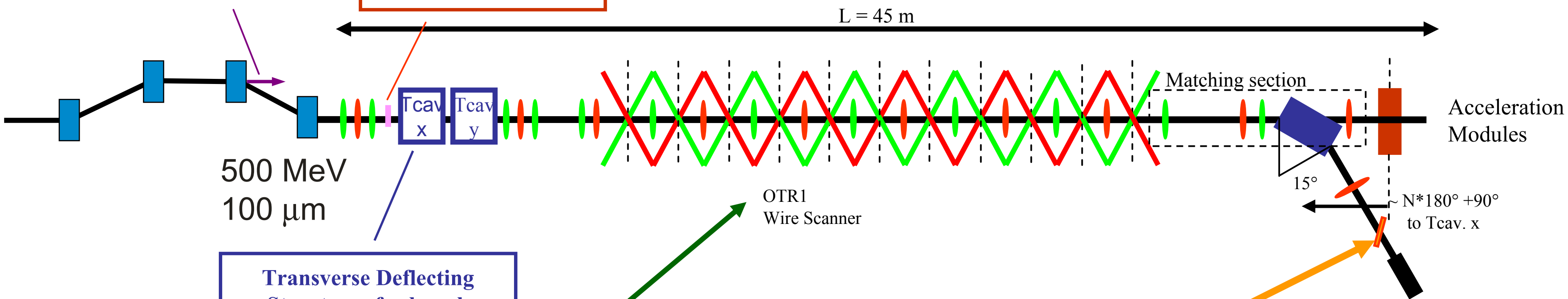
- Dedicated diagnostic sections for full characterisation of beam properties (emittance, long. beam profile, energy spread)
- Measurement of slice emittance and energy spread (tomography)
- High precision required
- Non-disruptive on-line monitoring (slow feedbacks, stabilisation)
- Single bunch measurements

Layout of Diagnostic Section BC1

Synchrotron radiation port for online bunch to bunch energy and energy spread measurements

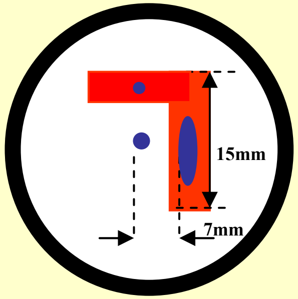
Electro-optical sampling for online bunch length measurements and determination the arrival time

Multi-screen slice emittance measurements



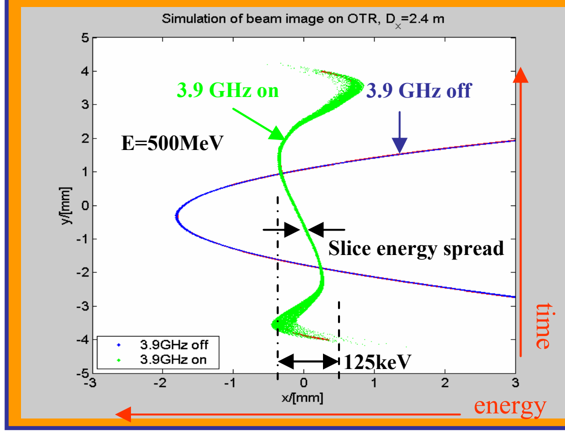
Transverse Deflecting Structures for bunch profile and slice emittance measurements

Off-axis screen design



- **kicker enable single bunch measurements**
- **Phase space tomography**
- **Slice emittance measurements**

Measurement of the correlated and residual energy spread of the bunch
Tuning of 3rd harmonic cavity
D = -2m, β_{OTR} = 0.3 m, Res.: ~ 7.9 keV



Operation modes for Diagnostic Section BC1

FEL mode - parasitic	**- Commissioning of long pulse trains** **- On-line beam characterisation** **- Correction of drifts** Medium beta function at TCAV (~15-25 m) Low space charge & chromatic effects Time resolution of TCAVs ~ 30 fs Slice emittance measurement using kickers (optic 1) Projected emittance measurement using kickers (optic 2) Kicked bunches dumped in collimator Dipole to dump is switched off
Diagnostic mode 1 **Long. Profile** - not parasitic	**- High resolution longitudinal profiling with TCAVS** High beta function at one TCAV (>50m) / special optic (optic 3) Small beta function at screen with 90 deg phase adv. Resolution better 10fs Dipole to dump is switched off
Diagnostic mode 2 **Energy spread** - not parasitic	**- Precise determination of RF phases & amplitudes** **- Studies of collective effects on longitudinal phase space** Dipole to dump is switched on Small horizontal and vertical beta at OTR and large dispersion (optic 4) Relative energy resolution at screen $\Delta E/E \sim 10^{-5}$ Single or few bunch mode
Diagnostic mode 3 **Long pulses** - not parasitic	**- Commissioning of LLRF upstream BC1** **- Studies of orbit stability and emittance variation across macro-pulse** Dipole to dump is switched on Off-axis screen in dispersive section Large beta function at dump screen (optic 5) Low loss operation in dump line Up to 800us? operation (1Hz) High resolution BPM based energy measurement across macro-pulse

Goal: Find layout for slice emittance measurements

Main criteria:

- Precision of slice emittance values
  - Mainly determined by measurement errors / fluctuations of slice widths (experience from FLASH: ~< 10%)
  - Depends strongly on bunch-/ slice mismatch

    (experience from FLASH: internal slice Mismatch B ~<1.5)
- Longitudinal resolution
  - at each screen: depends on the beam size (TCAV on) at the screen location
  - For slice emittance: limited by the screen with the smallest beam size → ratios of beam sizes at the screens are crucial

Soft criteria:

- Simplicity and cost effectiveness

  - symmetrical FODO lattice
  - small number of screens and cells
  - 'standard' measurements possible

Layout Optimization for slice emittance measurements

Matlab script used to scan the parameter space and find the best solutions (M Roehrs):

Constraints:

- Symmetrical FODO lattice
- Total length < 12 m
- max 8 cells
- max 8 OTR screens
- OTR screens in the centre of drifts

Variables:

- Number of cells
- Arrangement of OTR screens
- Phase advance FODO lattice
- Phase advance between TCAVs and FODO lattice

Standard options

Minimum beam size / maximum beam size seen on the screens with TCAVs on

You can gain by optimizing the position of the screens !!

Ψ_{cell} [°]	# cells	# screens	# screens per direct.	$\sigma_{min}/\sigma_{max}$	σ_ϵ [%]
60	2	3	3	0.50	26.2
45	3	4	4	0.40	15.4
30	5	6	6	0.27	10.5
22.5	7	8	8	0.19	8.7

RMS Emittance error for 10% beam size fluctuations, a mismatched beam / slice (B=1.5) and one image per screen (N=1)

- Problem : beam size scales with sin(Ψ)
- Example for 45°-option: 30fs maximum resolution → 75fs resolution for slice emittance
- The emittance error scales with $\sim 1/\sqrt{N}$

Optimized arrangements

→Irregular screen arrangements (still: screens in centres of drift sections)

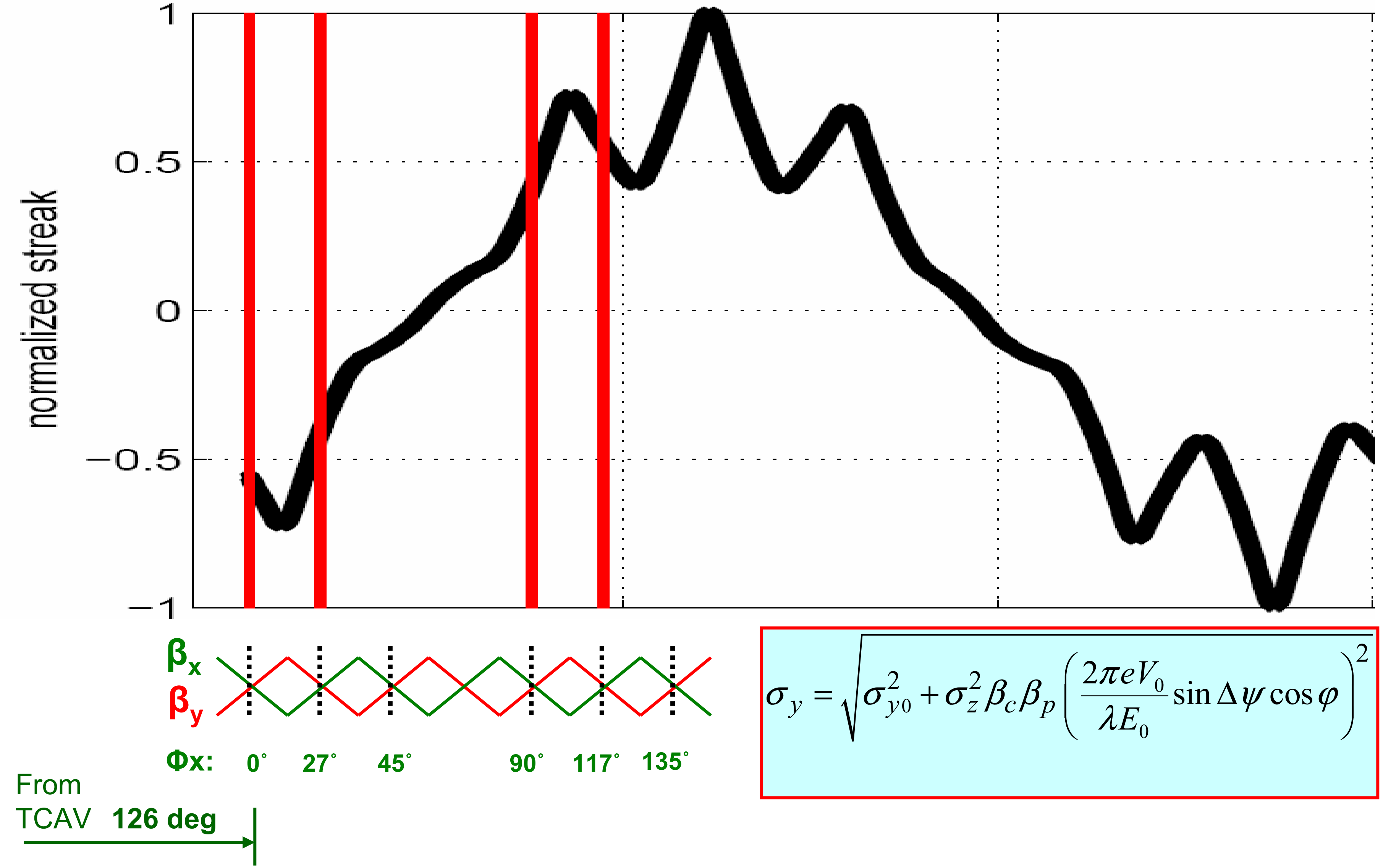
Ψ_{cell} [°]	# cells	# screens	# screens per direct.	$\sigma_{min}/\sigma_{max}$	σ_ϵ [%]
112	3	6	4	0.84	16.8
84	4	8	4	0.81	17.2
76	2	5	4	0.72	19.5
45	3	6	4	0.73	30.2

\+ Good long. Resolution: 30fs max. resolution→ 41fs resolution of slice emittance
\+ Tolerable emittance error: <= 30% for B=1.5 (10% for B=1)
\+ Moderate/Standard phase advance per cell (alignment errors)
\+ Comprises standard 45˚-option for projected emittance measurements
\- TCAV power / length has to be increased by ~24% since the beam size is not maximal at the screen locations
→ There are better solutions at larger Ψcell
→ Improvements possible by allowing arbitrary screen positions and asymmetric FODO lattices

76˚- lattice:
\+ less cells and screens
\+ smaller emittance error by mismatch
\+ screens at position of max. beam size (long. profile)
\- Standard 45˚-option not possible
\- Larger phase advance (alignment errors ?)

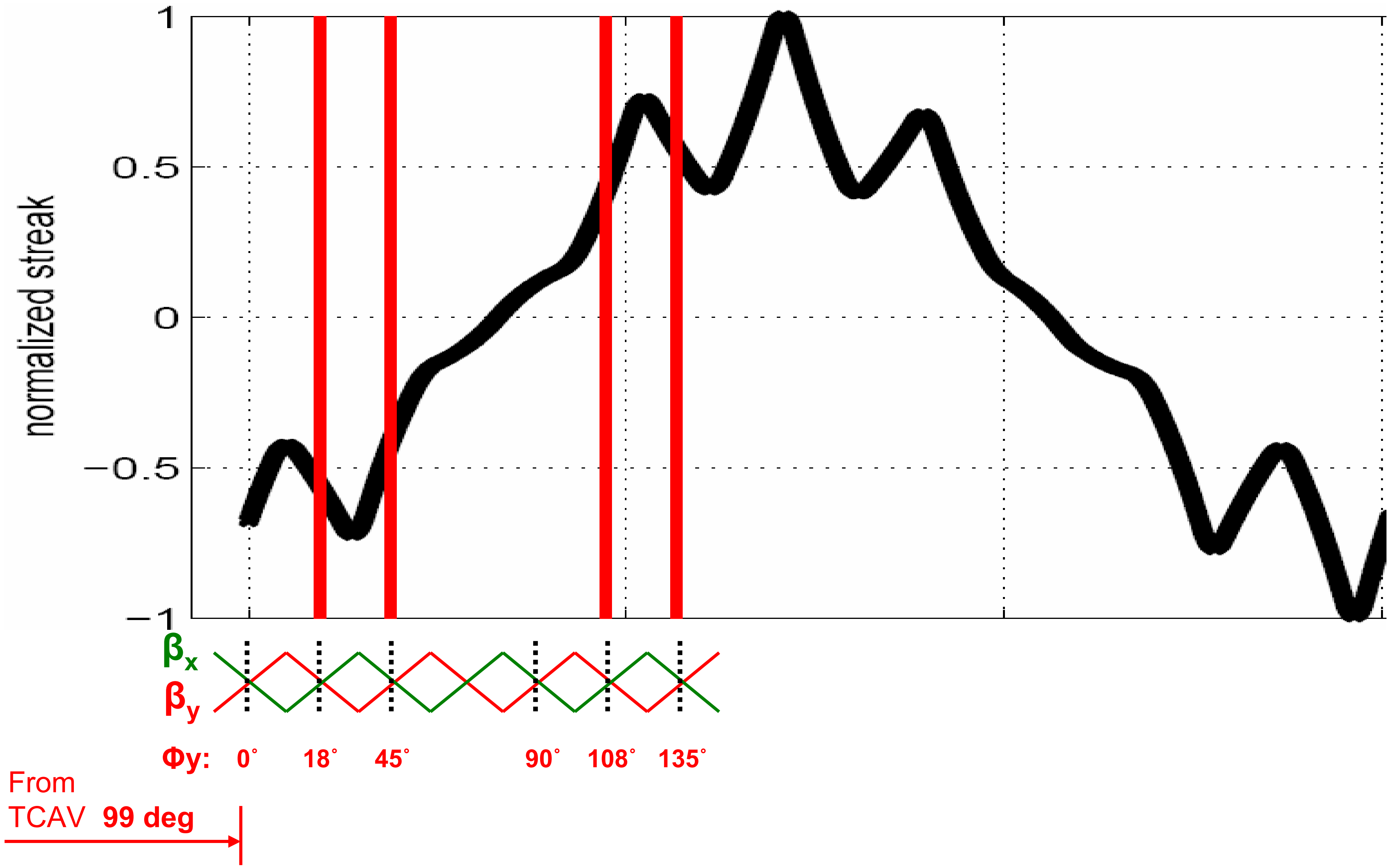
To be studied???

45° - FODO section

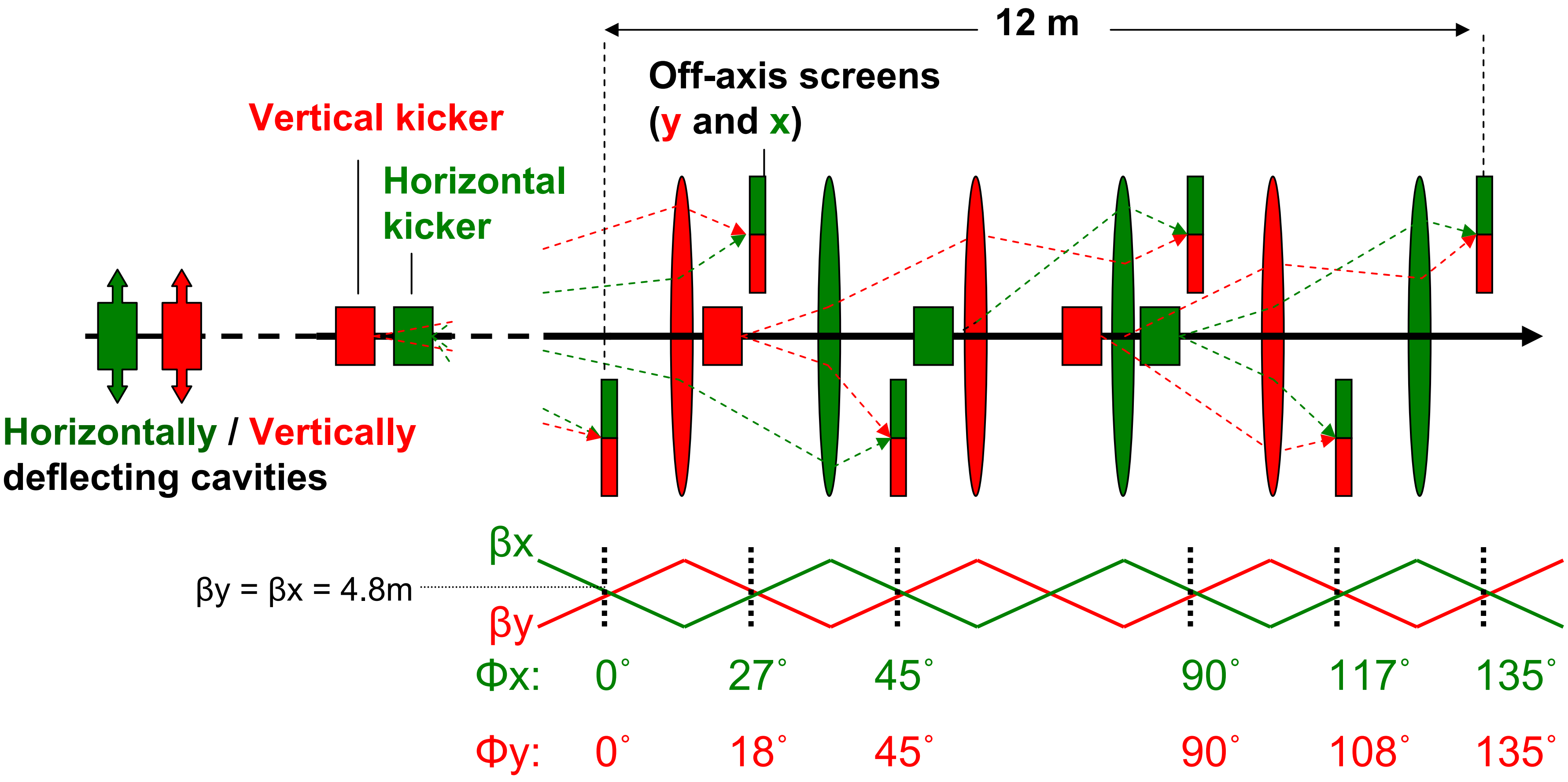


$$\sigma_y = \sqrt{\sigma_{y0}^2 + \sigma_z^2 \beta_c \beta_p \left(\frac{2\pi e V_0}{\lambda E_0} \sin \Delta\psi \cos\varphi \right)^2}$$

45°- FODO section

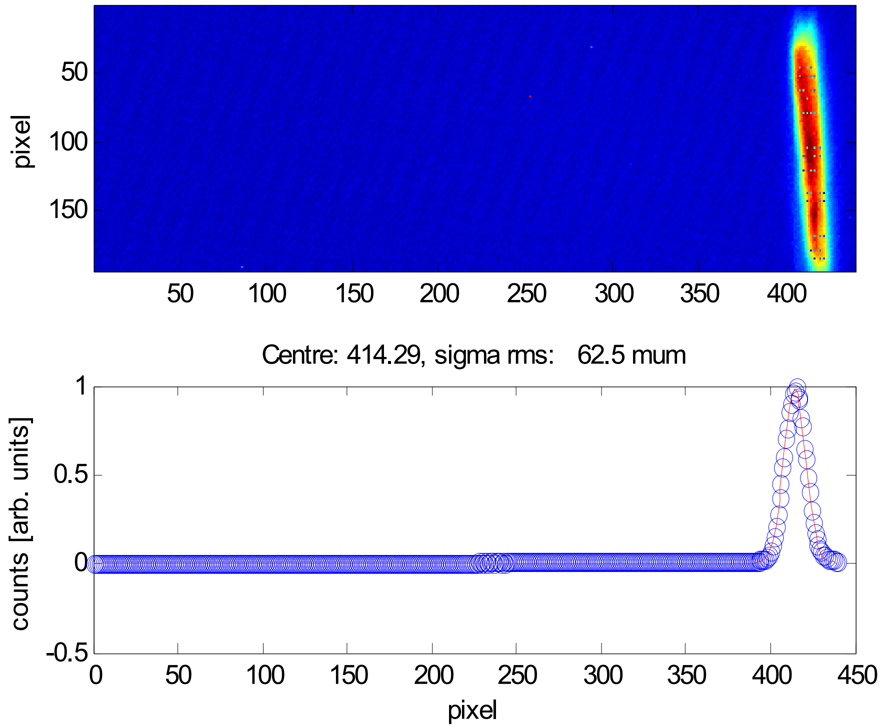


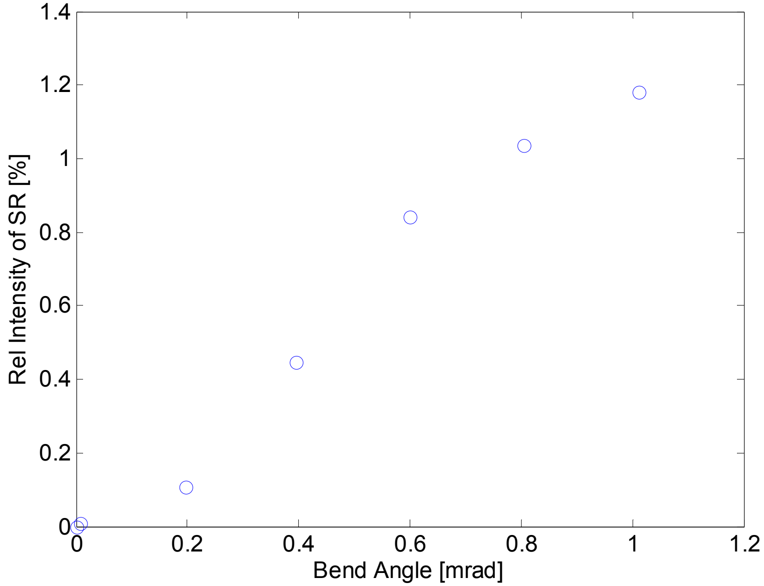
FODO section: kicker arrangement



Is background due to SR an issue?

Tests at FLASH under similar conditions:
380MeV, UBC3, 1 nC





Needs to be investigated further …

Optics layout criteria for 45˚- option:

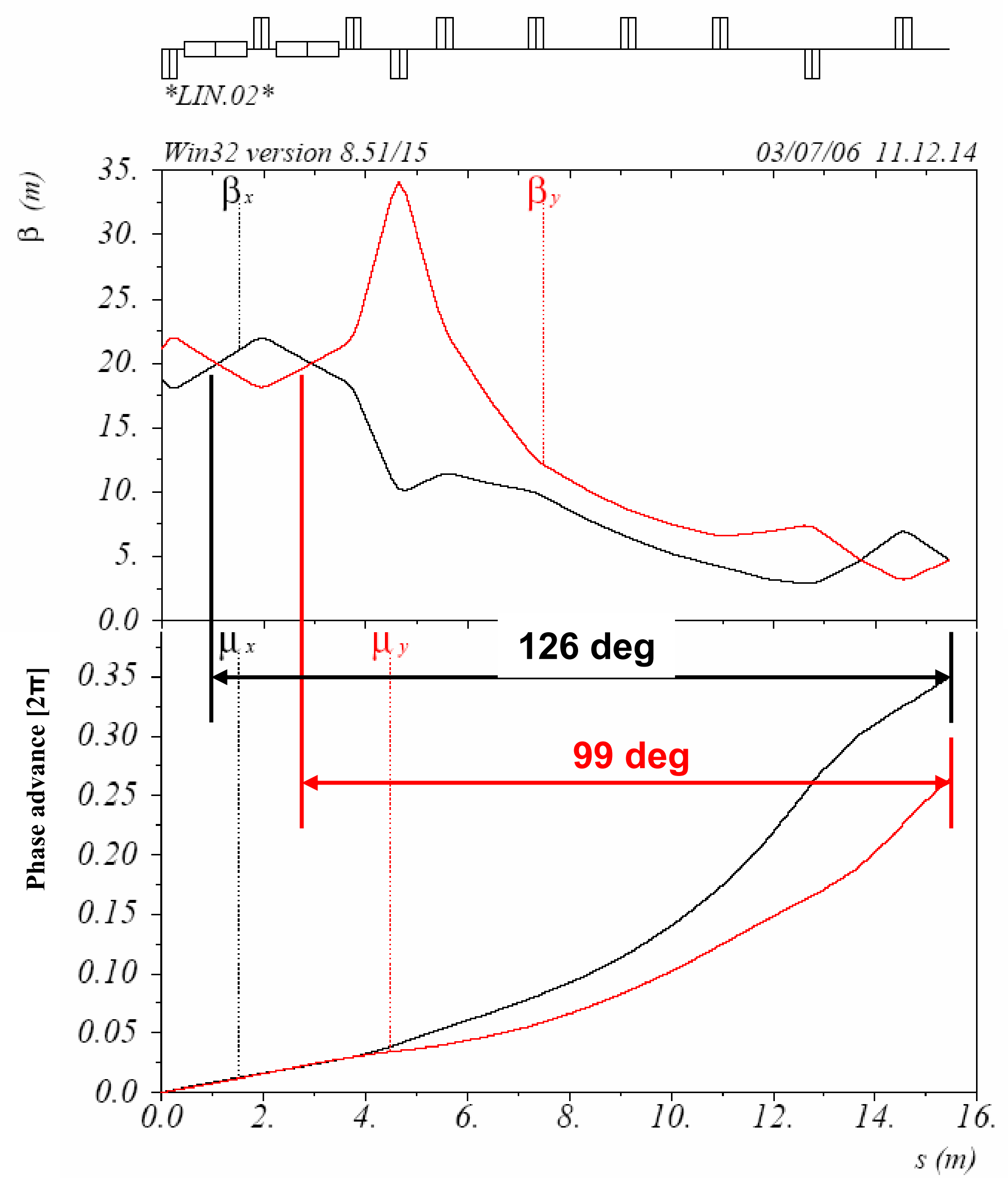
- Large beta functions at TCAVs
  β ~ 15-25m (constant along structure)

- Matching into FODO section with
  optimised phase advances
  β_y = 99° and **β_x = 126°**

- Total length: **< 45m**

Matching into FODO Section

TCAVs 1.2m-long in 1.5m drift



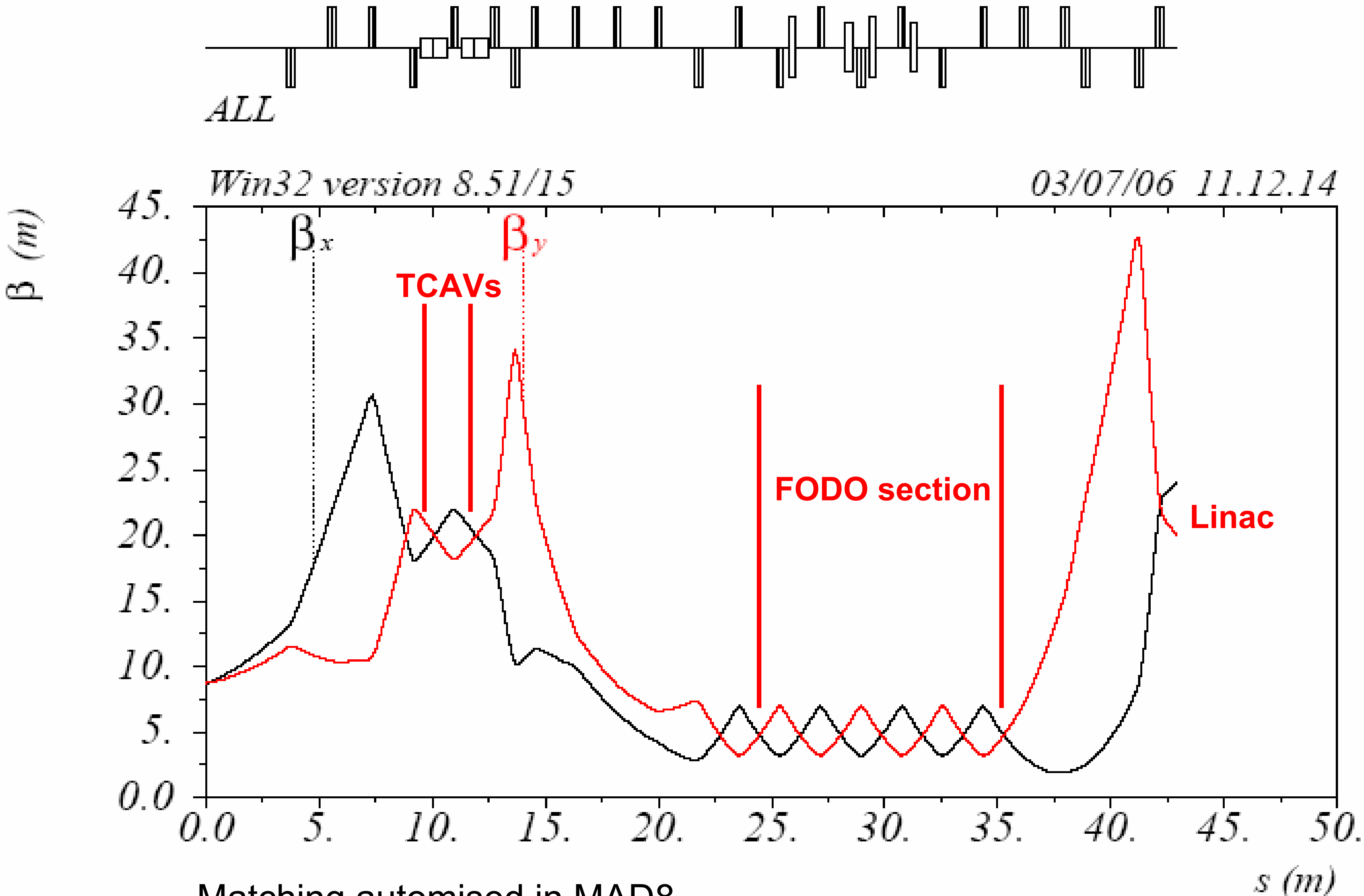
FODO section

Match 6 Twiss Parameters

Max beta function at TCAVs ~ 20 m

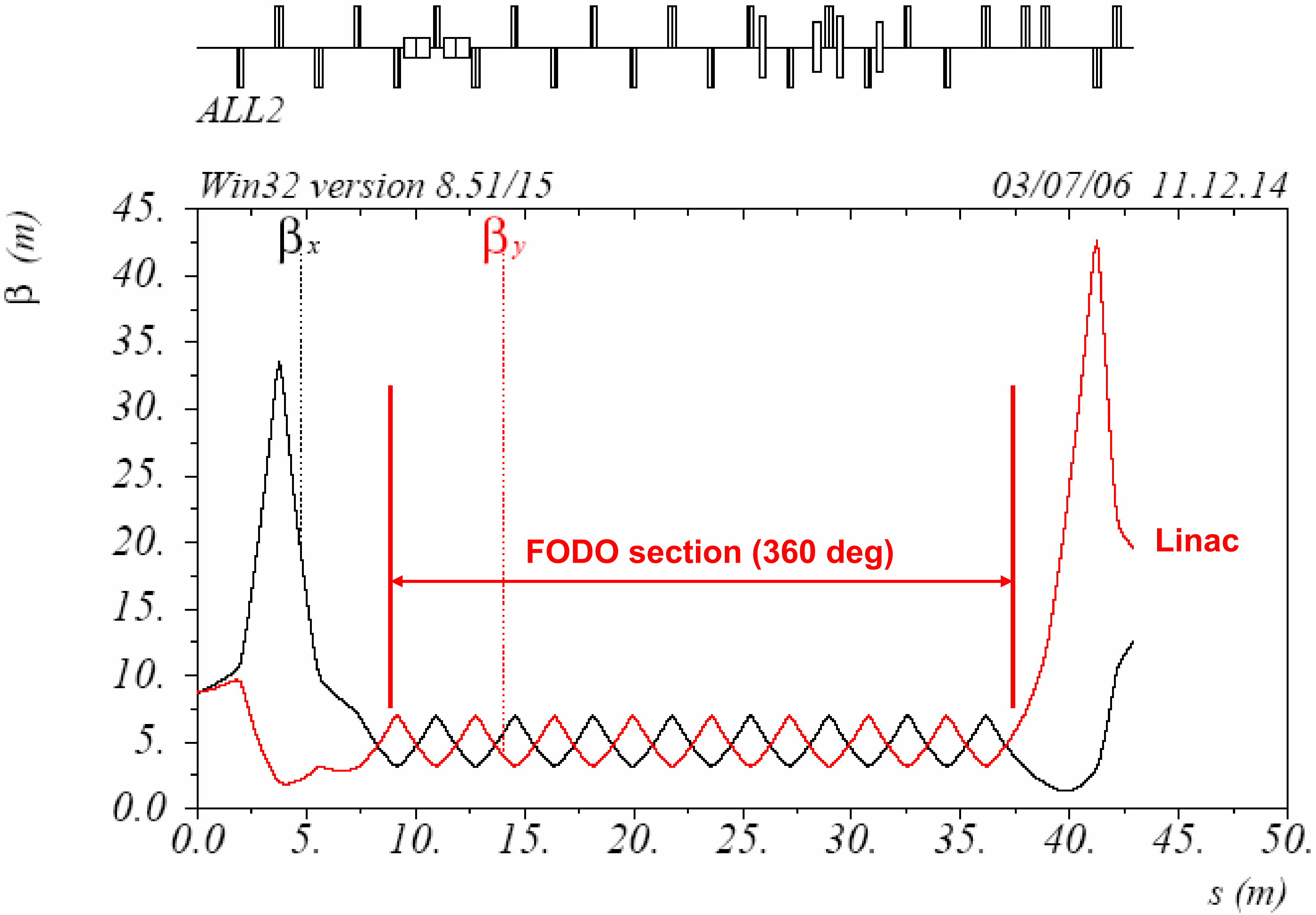
Better solutions with smaller phase advances?

Optics Layout Diagnostic Section 1
Slice emittance measurements (optic 1)

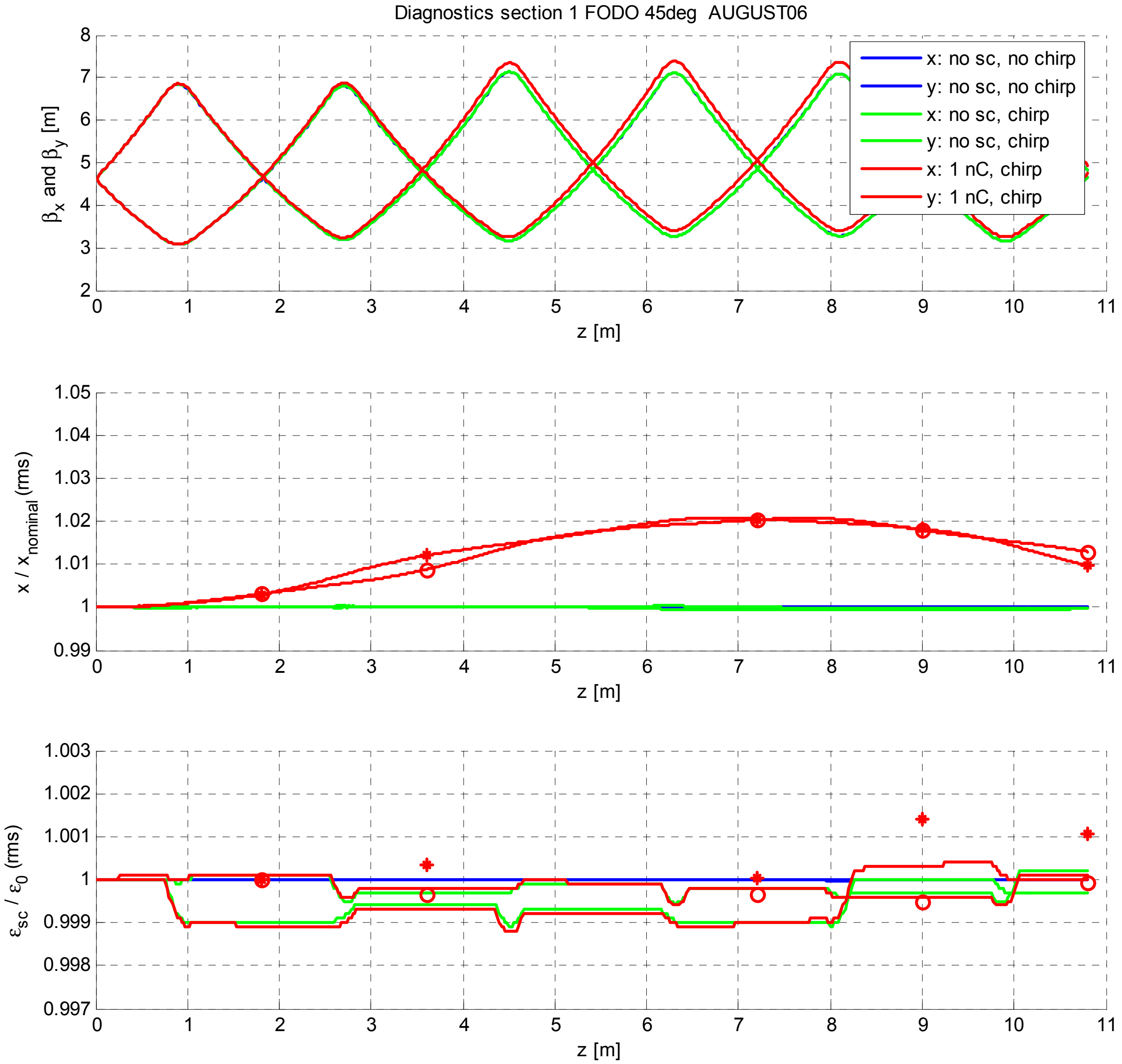


Matching automised in MAD8

Optics Layout Diagnostic Section 1
Projected emittance/ commissioning (optic 2)



Space charge / Chromaticity



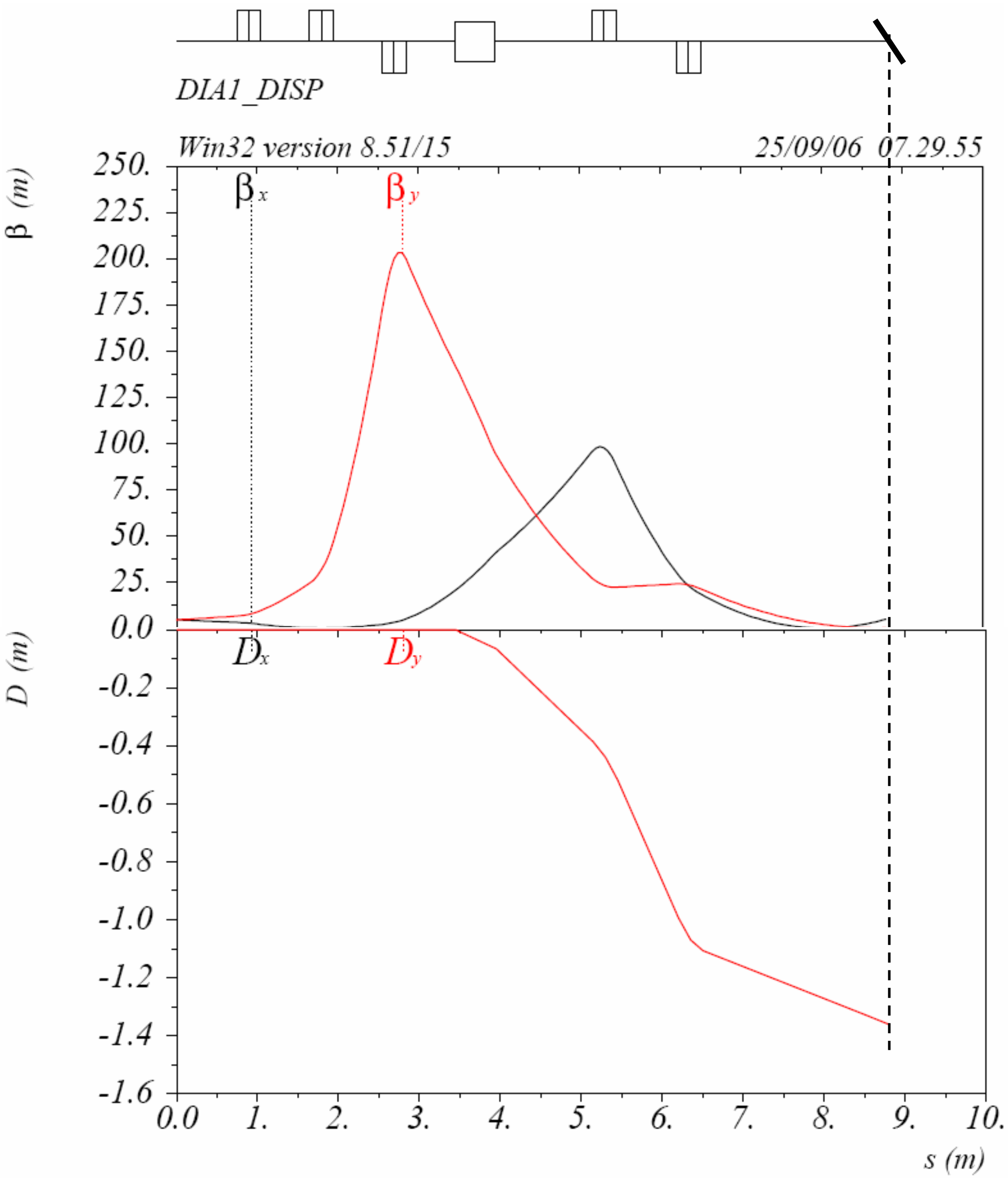
ASTRA simulations:
Space charge effects

- $\Delta\sigma/\sigma$ < 2%

- $\Delta\varepsilon/\varepsilon$ < 0.1%

Negligible compared to other errors.

Diagnostic mode 2: Energy Spread (optic 4)



Goal: $\Delta E/E \sim 10^{-5}$
→ $\Delta E \sim$ 5keV

from meas. at FLASH
Laser Heater (30 keV)

Values at screen:

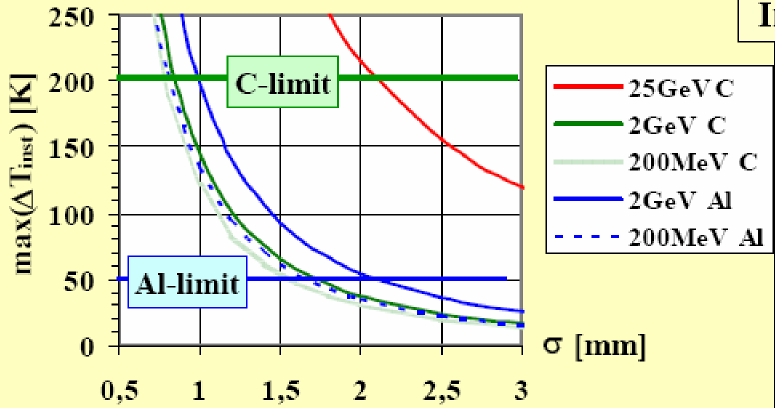
ßx = 1.992 m
ßy = 0.356 m
Dy = -1.327 m

→ $\Delta E/E \sim$ 1.5*10-5
ε_N = 1*10-6 µm

Higher order effects?
Chromaticity?
Needs to be studied

BC Dumps: Thermal Limits

Courtesy of M Schmitz, MIN



Instantaneous Heating

⇒ spot size limit for full bunch train

σ ≥ 1.7 - 2mm for Al dump resp.

σ ≥ 0.8 - 1mm for C dump

Average Heating

⇒ dP/dz limit w/o slow sweep

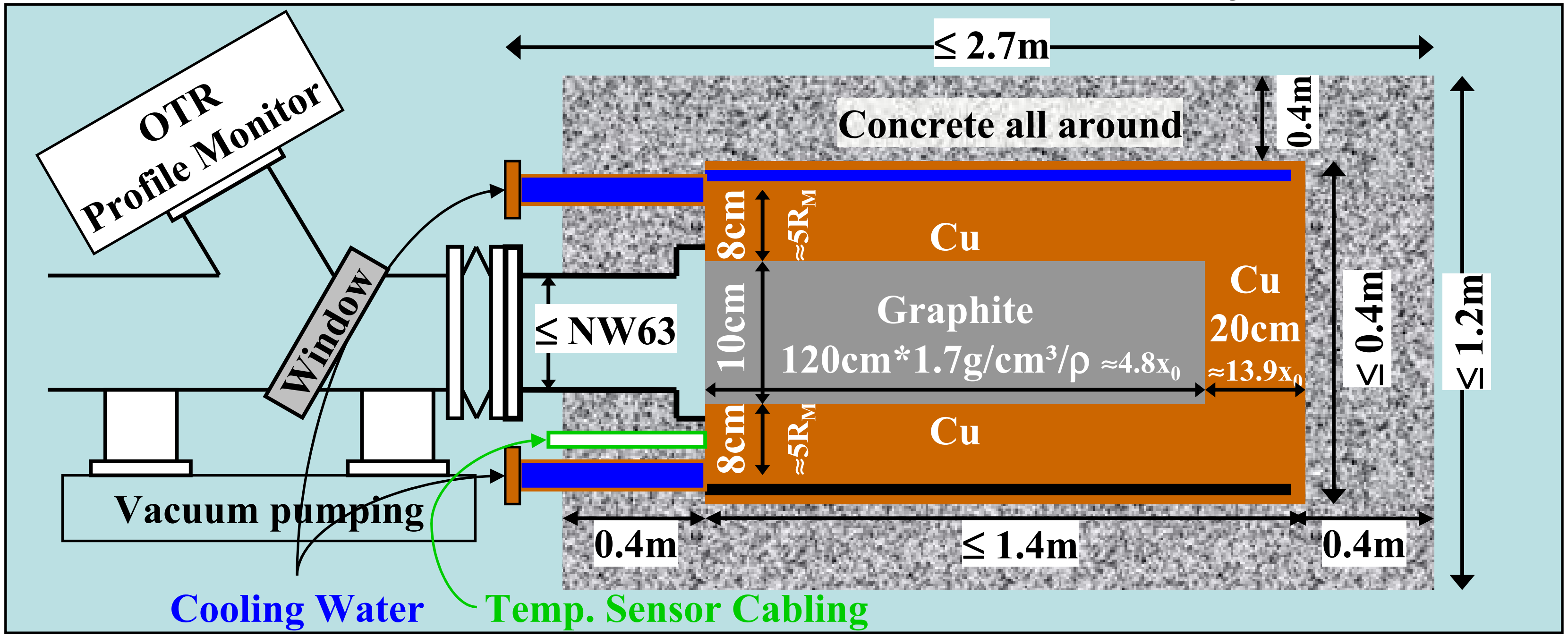
C-CU dump: 350W/cm @ σ =1mm

Al dump: 400W/cm @ σ =2mm

	max. beam: 40μA⇔10Hz			thermal op. limits of dump w/o slow sweep	
E_0	P_{ave}	dP/dz [W/cm]			
		C	Al	C-Cu: ≤ 350W/cm	Al: ≤ 400W/cm
2.5 GeV	100 kW	770	1800	16μA / 4Hz / 40kW	8μA / 2Hz / 20kW
2 GeV	80 kW	640	1500	20μA / 5Hz / 40kW	10μA / 2.5Hz / 20kW
500 MeV	20 kW	240	500	max. beam	32μA / 8Hz / 16kW
300 MeV	12 kW	190	380	max. beam	max. beam

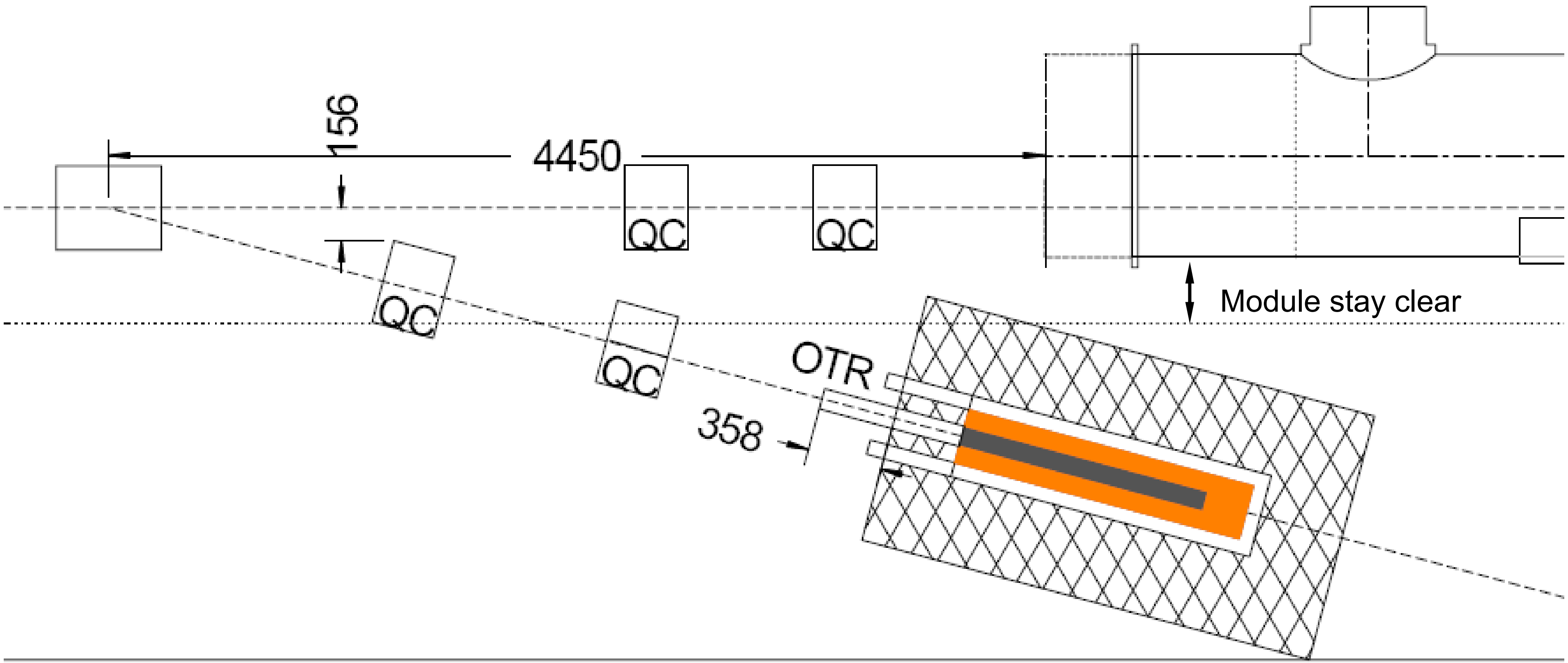
Sketch of BC1-Dumpmodule (C-Cu version) 500MeV

Courtesy of M Schmitz, MIN

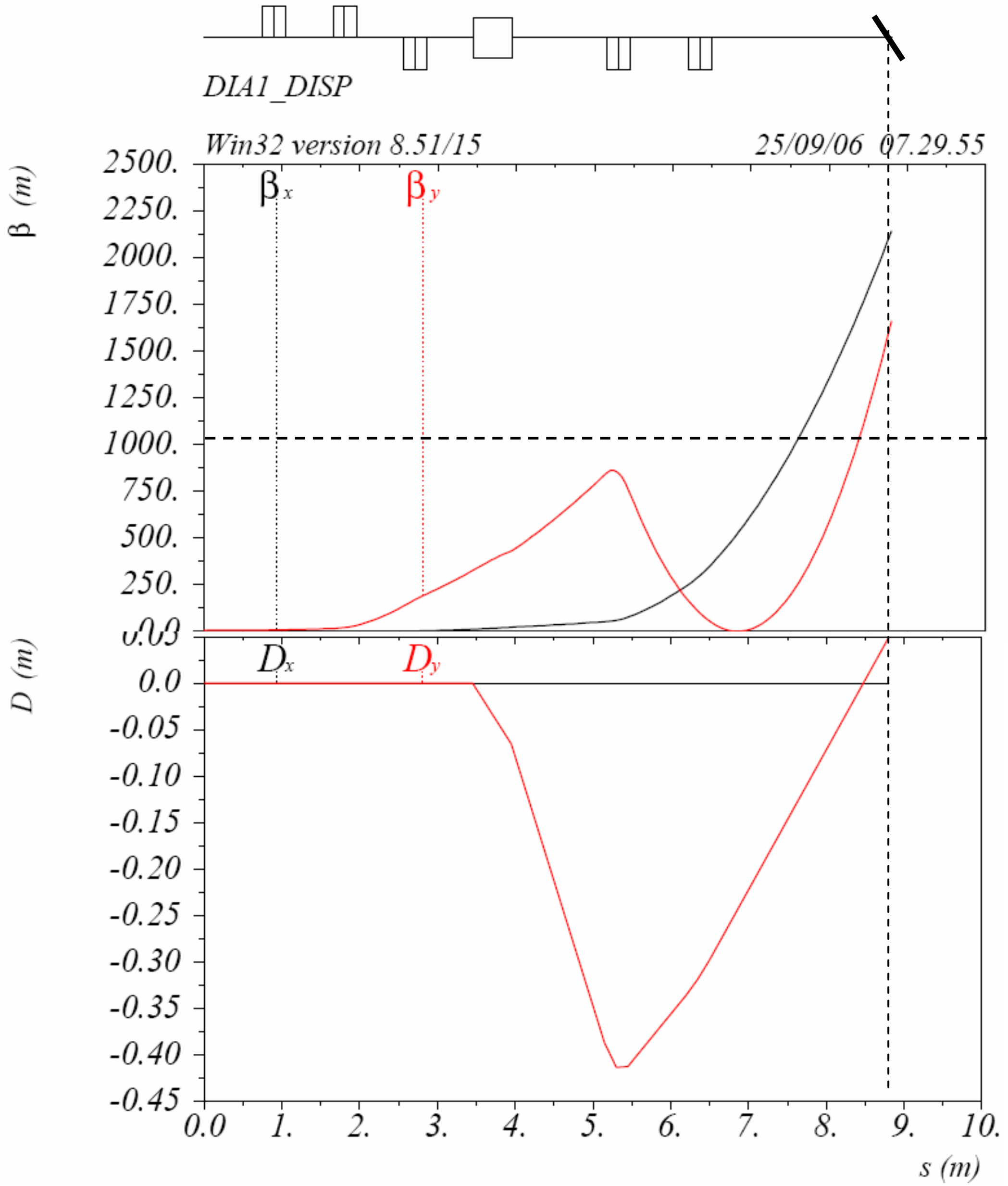


	density [kg/l]	volume (max. estimate)	mass (max. estimate)
Graphite core	~ 2	$120cm*\pi*(5cm)^2=9l$	~ 20kg
Cu back stop	~ 9	$20cm*\pi*(20cm)^2=25l$	~ 230kg
Cu radial layer	~ 9	$120cm*\pi*[(20cm)^2-(5cm)^2]=140l$	~ 1250kg
Concrete shield	~ 2	$220cm*\pi*(60cm)^2 - 140cm*\pi*(20cm)^2 =2300l$	~4600kg
	total	$220cm*\pi*(60cm)^2=2500$ l	~ 6100 kg

Diagnostic Dump BC1



Diagnostic mode 3: Long pulse trains (optic 5)



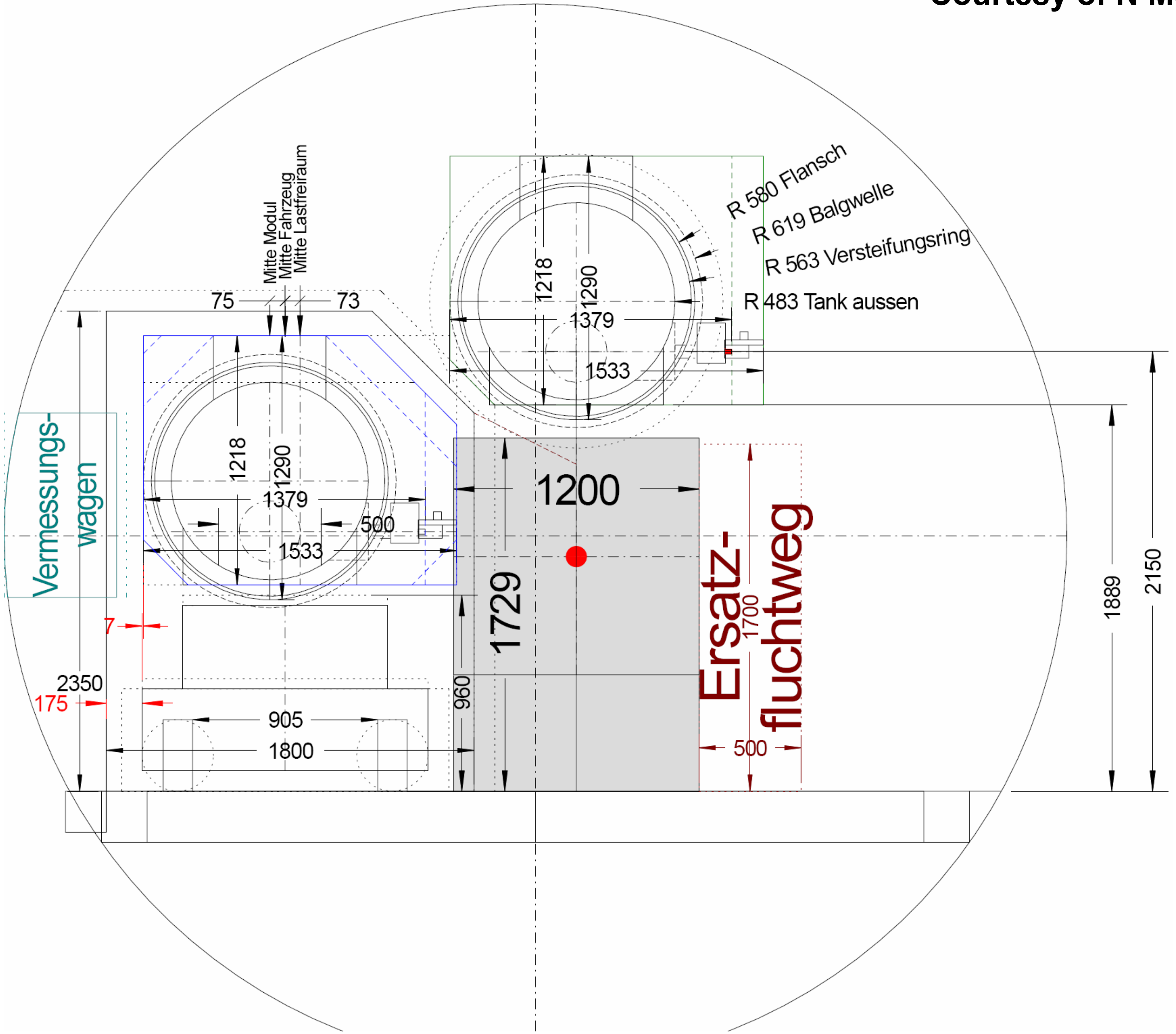
ßx = 1825 m

ßy = 1192 m

Dy = 3 mm

Diagnostic Dump BC1

Courtesy of N Meiners, MEA



Questions / Outlook

- Higher order effects? (Nina & Vladimir)
- Additional 2 screens for 45˚- lattice justified? (25% RF power more needed)
- 76˚- lattice to be studied?
- Layout of dump line?

- Tolerance studies
- Design of Diagnostics Section BC2 at 2 GeV

THE END